# The Impact of Anthropogenic Activities on Global Terrestrial Carbon Fluxes

# 論 文 内 容 要 旨

(NO. 1)

| 氏　　名 | Irina Melnikova | 提出年 | 令和 1 年 |
|---|---|---|---|
| 学位論文の<br>題　　目 | The Impact of Anthropogenic Activities on Global Terrestrial Carbon Fluxes.<br>(人為的活動が全球の陸域炭素フラックスに与えるインパクト) | | |

## 論 文 目 次

## 論 文 内 容 要 旨

The anthropogenic activity via land use change and fossil fuel and cement emissions substantially affect the Earth system, leading to the atmospheric CO2 increase that is recognized to be the main cause of the increasing global surface temperatures and consequent climate change. The unprecedented human-induced alterations in the Earth system since the Industrial Revolution drove the carbon cycle out of equilibrium, so that currently, the global biosphere acts as an uptake of more than half of anthropogenic carbon emissions. The largest and the most uncertain contributor to the interannual carbon uptake is land. An accurate understanding of the impact of anthropogenic activity on the land carbon uptake is crucial for quantifying the future carbon-climate feedbacks.

The land uptake is the net balance of gross primary production (GPP) and terrestrial ecosystem respiration (TER). GPP and TER exhibit large magnitudes and interannual variabilities that makes it difficult to distinguish the impacts of anthropogenic activity on the fluxes, i.e., the GPP and TER anthropogenic effects, from the impacts of natural climate variability, i.e. GPP and TER natural effects. Factorial simulations using several biosphere models have been used to estimate the effects of long-term climate change on global GPP and TER. However, no study has integrated large-ensemble climate simulation data into a biosphere model to realistically estimate global terrestrial carbon fluxes with associated uncertainty and to project the future changes in the carbon

fluxes by using statistical tools such as the probability density functions.

This thesis presents an approach to estimate the global GPP and TER with associated climate data-induced uncertainty that combines a diagnostic biosphere model with a large-ensemble climate simulation data set. I aim to distinguish the GPP and TER anthropogenic and natural effects in present 1952–2010 climate and future +2K and +4K warming climate simulations, identify the drivers and explore the probabilistic changes in GPP and TER with warming. In order to get realistic estimates of the global terrestrial GPP and TER with the associated input data-induced uncertainty, I force the biosphere model BEAMS with historical (HPB), "nonwarming" (HPB NAT), and future +2K and +4K (warmer than preindustrial) climate simulations of the Database for Policy Decision-Making for Future Climate Change (d4PDF). In order to identify the drivers of GPP and TER anthropogenic effects, I carry out several sensitivity experiments.

First, I provide evidence for an increasing anthropogenic effect on global terrestrial GPP. The GPP anthropogenic effect is driven by CO2 fertilization, which is projected to weaken or saturate by 2050–2150, depending on the representative concentration pathway scenario used. Model results suggest that shortwave radiation couples with ENSO conditions and volcanic eruptions to drive the natural GPP effect. While currently, the CO2 fertilization effect primarily drives the tropical GPP increase that dominates the global GPP anthropogenic effect, in the future warmer world, the climate drivers are projected to constrain the tropical GPP increase, so that the climate-driven non-tropical GPP increase takes over the dominancy of the GPP anthropogenic effect.

Second, I show that despite the benefits of CO2 fertilization effect on global GPP, the GPP anthropogenic effect cannot catch up with the increasing carbon emissions. Most likely, the major biosphere flux responsible for the increased atmospheric carbon growth is TER. The multi-ensemble model simulations show that both magnitude and interannual variability of TER increase in warmer climates with larger relative increase in high latitudes. The higher TER variability corresponds to higher TER in the tropics and mid-to-high northern latitudes. The main driver of future TER anthropogenic effect is temperature, while the effects of vapor pressure and

precipitation are uncertain due to regional uncertainties in the climate projections. While in 1952–2010, temperature played only a minor role in the TER anthropogenic effect, its role is projected to increase in the future warmer climates because the contribution of temperature in driving TER increases with warming exponentially according to Q10 function.

Overall, the findings of the present study clarify the mechanism of the changes in land carbon fluxes due to the impacts of the anthropogenic activity on the Earth system. I show that both GPP and TER anthropogenic effects increased in the past, and are projected to increase in future warmer climates. While the GPP anthropogenic effect is the largest in the tropics, the TER anthropogenic effect exhibits bipolarity. While in the future climate simulations, the GPP anthropogenic effect is projected to weaken at higher CO2 concentrations, no synchronic weakening is projected for the TER anthropogenic effect with higher temperatures. The disproportional increase in TER with warming towards high latitudes that are a massive reservoir of soil carbon highlight the need in the urgent action for stronger mitigation of anthropogenic emissions.

別　紙

論文審査の結果の要旨

人間活動は土地利用改変，化石燃料の排出などを通して，地球温暖化の主要因である大気中の二酸化炭素の増加を引き起こしている。産業革命後の二酸化炭素増加の半分程度は陸域生態系が吸収していると考えられるが，その寄与については不確実性が高い。陸域での正味の二酸化炭素吸収量（炭素フラックス）は，生態系の光合成による総一次生産量（GPP）と陸域生態系呼吸量（TER）のバランスで決まる。Irina MELNIKOVA の博士論文では，全球の GPP と TER に対する人為的活動の影響を陸域生物圏モデル（BEAMS）により評価したものである。モデルの入力データとして大規模アンサンブル気候シミュレーションデータ（d4PDF）を用いることによって，不確実性も評価したことは，これまでにない試みである。第２章に使用したデータと研究手法が述べられている。

第３章では現在気候（1952～2010 年）における GPP への人為的活動の影響を評価した。まず，入力データ d4PDF の評価を行った上で，BEAMS を d4PDF 現在気候のデータで駆動し，観測ベースや他のモデルによる GPP に関する先行研究と比較し，モデルの妥当性を評価した。続いて，d4PDF 非温暖化実験データを用いて求めた GPP の結果と比較することにより，人為的活動の影響を評価した。その結果，人為的活動の影響がこの 60 年で増加し，それは入力データの不確実性を上回るものであった。GPP の増加は主に二酸化炭素の施肥効果によるものであり，2050～2150 年には頭打ちになるとみられることがわかった。

第４章では温暖化による将来の TER の変化を d4PDF の 2 度上昇と 4 度上昇データを用いて，確率情報をつけて評価した。TER の大きさと年々変動はともに将来増加し，特に高緯度で増加が顕著であることを明らかにした。現状での TER の増加は主に植物呼吸の寄与が大きいが，将来は温度上昇による土壌呼吸増加の寄与が増すと予測された。

陸域生態系の炭素フラックスという大変困難な課題に，陸域モデルと大規模データを用いて取り組んだ本論文は高く評価でき，本人が自立して研究活動を行うに必要な高度の研究能力と学識を有することを示している。したがって，Irina MELNIKOVA 提出の博士論文は，博士（理学）の学位論文として合格と認める。